June 17, 2002

Attachment 2
Sprint Reconsideration Petition, ET Docket 98-153

Review and Analysis of the Sprint/Time Domain UWB-to-PCS Interference Tests

Introduction

Two UWB-to-PCS interference tests were described in Attachment 2 to a joint Sprint/Time Domain filing on September 12, 2000.[1] The first test was performed in an anechoic chamber using an IS-95 PCS base station simulator to communicate with the PCS handset. The second test took place at Sprint's live system testbed, using an operational base station.

The results of the second test were misinterpreted by Time Domain in subsequent filings, and appear to have been misinterpreted by the Commission as well in reaching its conclusions regarding appropriate UWB emission levels. The purpose of this paper is to provide a concise review of relevant results from the tests and to correct those misinterpretations.

The Anechoic Chamber Test

The net result of the anechoic chamber test was to confirm the sensitivity of the PCS handset, and to establish the free-space coupling between the UWB transmitter and the PCS handset; that is, for a given separation distance, the effective UWB interference power received from the PCS handset.

The downlink power to the handset was controlled by manually varying the power output of the base station simulator. The traffic channel power was set to a fixed 10.3 dB below the total transmitted downlink power (i.e., about 9.3% of the total power was allocated to the traffic channel). There was no automatic power control. Without the UWB interference, the PCS handset began to exhibit frame errors as the E_b/N_0 was reduced to about 5 dB, consistent with the Telcordia Model, which conservatively assumed an E_b/N_0 threshold of 6.2 dB.[2]

UWB interference was added from one Time Domain UWB device, and it was determined by analysis of the data that for free-space path loss, which is appropriate

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[1] *See* Sprint/Time Domain Ex Parte, ET Docket No. 98-153 (Sept. 12, 2000), Attachment 2, Dr. Jay Padgett, Senior Research Scientist, Telcordia Technologies, *Summary of Testing Performed by Sprint PCS and Time Domain to Characterize the Effect of Ultra Wideband (UWB) Devices on an IS-95 PCS System* (Sept. 12, 2000)(hereafter, Sprint/Time Domain Test Results)

[2] *See* Sprint/Time Domain Ex Parte, ET Docket No. 98-153 (Sept. 12, 2000), Attachment 1, Dr. Jay Padgett, Senior Research Scientist, Telcordia Technologies, *A Model for Calculating the Effect of UWB Interference on a CDMA PCS System* (Sept. 12, 2000)(hereafter, Telcordia Model) at 2.

when the UWB transmitter is within several meters of the PCS handset, the effective UWB interference power (for the UWB device and handset used in the test) can be described as a function of distance by:

$$I_{uwb} = -95 - 20\log d \quad \text{dBm} \tag{1}$$

where d is the distance between the UWB transmitter and the PCS handset in meters.

The Live System Test

The second set of tests was performed on the IS-95 testbed operated by Sprint PCS. Although some of the data were lost, enough remained to confirm that the UWB interference affected the PCS handset as predicted by the Telcordia Model. In the case for which adequate data remained, only the overhead channels (pilot, sync, paging) and a single traffic channel were transmitted from the PCS base station. Only a single base station was active.

At the location of the handset, the RSSI (total received forward link power) varied between –96 and –92 dBm. This variation was presumably due to multipath fading. The transmitted traffic channel power varied within the range 16 to 21 dBm without the UWB interference. The variation in the transmitted traffic channel power is expected, due to the signal fading, as well as the normal variations due to the way in which the IS-95 downlink power control operates. When the transmitting UWB device was placed within one foot of the PCS handset, the transmitted traffic channel power increased noticeably, up to its apparent maximum value of 29 dBm. Eventually, the call dropped.

It can be seen with some simple analysis that this is the expected result, based on the way in which an IS-95 CDMA PCS system operates, as described in Attachment 1 to Sprint's reconsideration petition.[3] In that test case, only a single sector was activated, so there was no other-cell interference, and the required power allocation for the single traffic channel is

$$a_{traf} = \frac{1}{M}\left(\frac{N}{P_{rx}} + F_{no}\left(1 - a_{traf}\right) + \frac{I_{uwb}}{P_{rx}}\right) \tag{2}$$

or

$$a_{traf} = \frac{1}{M + F_{no}}\left(\frac{N}{P_{rx}} + F_{no} + \frac{I_{uwb}}{P_{rx}}\right) \cong \frac{1}{M}\left(\frac{N}{P_{rx}} + F_{no} + \frac{I_{uwb}}{P_{rx}}\right) \tag{3}$$

[3] *See* Operational Overview of the IS-95 CDMA Downlink, Attachment 1 to Sprint Petition for Reconsideration, ET Docket No. 98-153.

where M is the jamming margin for the traffic channel (assumed 13.2 dB), N is the PCS handset thermal noise floor, F_{no} is the downlink non-orthogonality factor ($0 \le F_{no} \le 1$), and I_{uwb} is the interference received from the UWB transmitter at the PCS handset. The approximation is valid because $F_{no} << M$.

Since the sector was not loaded in this test, the base station was not transmitting its maximum power and it is more useful to express (3) in terms of received traffic channel power than in terms of the fractional power allocation, by multiplying both sides by P_{rx}:

$$P_{rx,traf} = a_{traf} P_{rx} = \frac{1}{M}\left(N + F_{no}P_{rx} + I_{uwb}\right) \tag{4}$$

In the test, P_{rx} fluctuated about an average value of –94 dBm.

The maximum base station transmit power (into the antenna terminals) is 41 or 42 dBm, depending on the power amplifier that is used. The overhead channel allocation is typically on the order of 18% and is not power-controlled (since it must cover the entire cell). The total transmitted overhead power is therefore about 33.6 to 34.6 dBm. For the baseline case (no UWB signal), the transmitted traffic channel power fluctuated about an average of 18.5 dBm. The total transmitted power therefore is 33.7 to 34.7 dBm (taken as 35 dBm in the discussion in the Sprint/Time Domain Test Results). The average path loss, including antenna effects, is $L = P_{TX} - P_{rx}$, or about 127.7 to 128.7 dB. $L = 128\,\text{dB}$ will be used here for the calculations.

From (4), the additional received traffic channel power required to compensate for the UWB interference is

$$\Delta P_{rx,traf} = \frac{I_{uwb}}{M} \tag{5}$$

Using (1), with a 128-dB path loss and a 13.2-dB jamming margin, $\Delta P_{rx,traf}$ as a function of UWB separation distance is

$$\Delta P_{TX,traf} = 10^{(128-95-20\log d-13.2)/10} = \frac{95.5}{d^2}\ \text{mW} \tag{6}$$

The baseline average transmit power is 18.5 dBm, or 70.8 mW, so the total traffic channel transmit power is

$$P_{TX,traf} = 70.8 + \frac{95.5}{d^2} \tag{7}$$

The table below shows $P_{TX,traf}$ for the values of d used in the test.

d (m)	$P_{TX,traf}$ (dBm)
0.3	30.5
1	22.2
3	19.1

With IS-95, there is an upper limit on the traffic channel transmit power, which appears to have been set to 29 dBm in the system used for the tests. The required power for a UWB separation of 0.3 m (about 1 foot) exceeds this level slightly, so the call would be expected to drop eventually, which is what happened. At 3 meters, the increased power required to adjust to the UWB interference in this case would have been about 0.5 dB, so it is not surprising that no significant effect was observed in the test, at that distance (for a lower value of P_{rx}, such as would occur near the cell boundary, this would not be the case).

The remaining distance tested, 1 meter, should cause an increase of about 3 to 4 dB according to the above calculations, but this does not seem to have been the case. It is quite possible that destructive cancellation from a ground reflection reduced the UWB interference incident at the PCS handset in this case. The effect can be calculated with the help of Figure 1.

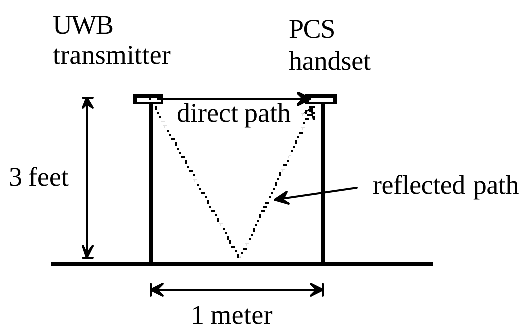

Figure 1: Geometry for calculating the effect of the ground reflection

During the test, the UWB transmitter and the PCS handset were kept 3 feet above the ground as nearly as possible. With a horizontal separation of 1 meter, the total distance traveled over the reflected path would be about 2.08 meters. The wavelength at 1970 MHz is 0.1523 meters, so if the direct and reflected path lengths differ by an odd multiple of $l/2 = 0.076$ m, the direct and reflected rays would be 180° out of phase. In that case, if E_d is the amplitude of the received field strength of the direct ray at the PCS handset, then the resultant field strength is $E_r = E_d(1 - 1/2.08) = 0.52E_d$, and $20\log(E_r/E_d) = -5.7$ dB. Thus, the ground reflection could reduce the received UWB interference by 5.7 dB with this particular geometry. In that case, the received UWB interference would be –100.7 dBm and $P_{TX,traf}$ would be 19.8 dBm. While such a small increase in the average traffic channel power (1.3 dB) would impact the overall performance of an operational IS-95 system, it may have escaped notice in the test.

Because the exact phase relationship of the direct and reflected rays is sensitive to small changes in the elevations and horizontal separation of the PCS handset and UWB transmitter, due to the relatively small half-wavelength, it cannot be determined precisely (especially in retrospect). However, the explanation given here is consistent with what as observed. ***It should be noted that this case serves as an example of the risk of assigning too much significance to a single data point in a single test.***

At the 1-foot separation, the direct path is about 0.3 meters and the reflected path is about 2 meters, so $E_r \cong E_d(1-0.3/2) = 0.85E_d$, giving $20\log(E_r/E_d) = -1.4\,\text{dB}$. If the direct and reflected rays were exactly in phase, then $E_r \cong 1.15E_d$ and $20\log(E_r/E_d) = 1.2\,\text{dB}$, so the uncertainty due to the ground reflection is much less significant at the 1-foot distance.

Discussion

Time Domain Corporation ("TDC") discusses the tests summarized above in its October 27, 2002 reply comments.[4] TDC attempts to apply the Telcordia Model to the test results but does so incorrectly. TDC states:

> The recording starts at 4:16 PM with the TM-UWB transmitter turned off. The received CDMA signal strength was averaging –94 dBm at the handset. Using the relationship $a = \frac{1}{M_J}\left(\frac{N}{P_{rx}} + F_{no}\right)$, the model predicts a rise in the forward power allocation of 2.6 dB, given a received signal strength of –94 dBm and outdoor non-orthogonality factor of 0.1.[5]

Using $M_J = 13.2\,\text{dB}$ and $N = -105\,\text{dBm}$, this calculation yields $a = 0.0086$. It is unclear how TDC arrived at the 2.6 dB figure, or to what baseline the "rise" in the power allocation was begin compared. The case described by TDC is actually the baseline. Further, there seems to have been no basis for the choice of $F_{no} = 0.1$.

TDC then states:

> The TM-UWB device was turned on a 4:20 PM at a distance of 3 meters from the CDMA handset. Based on the model the relationship $\Delta a = \frac{I_{uwb1}}{d^2 M_J P_{rx}}$ predicts that the presence [of the] TM-UWB signal should

[4] *See* Time Domain Corporation, Reply Comments, Appendix A, ET Docket 98-153, October 27, 2000 (hereafter, TDC Appendix A).

[5] TDC Appendix A at pp. 7-8.

> cause the system to raise the forward power allocation by 2.3 dBm, but any rise is totally masked by other noise and no TM-UWB impact is apparent.[6]

With $I_{uwb1} = -95\,\text{dBm}$, the equation used by TDC gives $\Delta a = 0.0042$. From (7) the actual increase in transmit power would be about 10 mW, so the increase in transmit power (in dB) would be less than 1 dB as shown in the table above (due to the 18.5 dBm baseline traffic channel transmit power). Again, it is unclear how TDC arrived at its result, but it seems to have misunderstood the Model and, accordingly, misinterpreted the test results.

Unfortunately, TDC's misunderstanding of the Telcordia Model and how it relates to the field test results seems to have influenced the Commission in its decisions regarding acceptable UWB emission limits. The UWB Order states:

> On the other hand, TDC believes that the theoretical model of Telcordia does not accurately describe the results of real world open field testing, adding that it is not possible for the PCS receivers to detect UWB emissions even at separation distances of less than 1 meter. It stated that the PCS phone performance was dramatically better in an anechoic chamber than in an open field even though the base station was clearly visible to the handset and the propagation path was unobstructed.[7]

As explained above, the field test results are, in fact, consistent with the Telcordia Model. Furthermore, comparing the open field tests to the anechoic chamber tests is an apples-to-oranges comparison. The anechoic chamber tests served mainly to determine the parameters for the free-space coupling between the UWB transmitter and the PCS handset necessary to properly interpret the field test data. In contrast, the field tests served mainly to test the impact of UWB interference on a operational system with downlink power control and a limit on the maximum traffic channel transmit power.

The UWB Order further states:

> We find that the testing in the anechoic chamber permitted the PCS receiver to function properly down to the thermal noise floor of the receiver. Once this equipment was placed outdoors in a simulated environment, the UWB emissions had no significant effect except at distances less than 1 meter.[8]

In actuality, the PCS handset receiver operated below its noise floor in both the anechoic chamber test and the outdoor test. In the anechoic chamber test, the total received signal was about –105 dBm. The traffic channel power allocation was –10.3 dB, so the desired signal power was –115.3 dBm, about 10 dB below the noise floor. In the field test, the

[6] *Id*. at p. 8.

[7] UWB Order at ¶ 157.

[8] UWB Order at ¶ 159.

calculations above indicate that the desired signal power was about –109.5 dBm, or about 4.5 dB below the noise floor. In-cell interference in the case of the field test, due to the lack of perfect orthogonality of the received downlink as represented by the term $F_{no}P_{rx}$ in (4), likely accounts for the difference.

The fact that a 1-foot separation was required to cause the required traffic channel power to exceed its maximum and drop the call in the field tests should not be used as a measure of the immunity of PCS handsets to UWB interference. The total received power from the downlink was –94 dBm, which is about 10 dB above the normal cell boundary signal level. In terms of area coverage, the last 10 dB represents about 75% of the cell area, so it is not appropriate to use such a high signal level to measure the impact of UWB interference on PCS handsets. This can easily be seen as follows. If path loss varies as d^{g}, where *d* is the separation between the PCS handset and base, then for every doubling of distance, the signal strength is reduced by a factor of $10g \log 2 = 3g$ dB. For example, with $g = 3.3$, the signal decays at a rate of 10 dB per doubling of distance, or 10 dB per octave. Thus, if the cell boundary is –104 dBm, then –94 dBm represents a contour halfway between the base station and the cell boundary. The area inside the –94 dBm contour therefore represents only 25% of the cell area. Setting UWB interference levels based on the seventy-fifth percentile of the PCS signal level distribution is not consistent with good engineering practice.

The field test results serve mainly to confirm that the Telcordia Model accurately describes the operation of an IS-95 CDMA system and how it is affected by UWB interference. Modeling, spot-checked by test results, would appear to be a much better tool for calculating UWB interference effects, since it allows a large number of scenarios to be explored quickly and economically.

Overall, the Commission seems to have based its conclusions about UWB interference impact to PCS on a single data point from a test that has been misrepresented by UWB proponents. In fact, the test results are consistent with the Model, as demonstrated above.